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The influence of soil pollution on soil microbial biomass and nematode community structure in Navoiy Industrial Park, Uzbekistan

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Abstract

The effects of ammonium-rich and heavy-metal air pollution produced by the industrial enterprises at Navoiy (Uzbekistan) on soil free-living nematodes and microbial population activities was investigated in soil samples collected in a 5-km radius surrounding the industrial enterprises. At each location (n=4), soil samples were collected from the upper layer (0–10 cm) for determination of soil moisture (SM), total organic carbon (C_{org}), total soluble nitrogen (TSN), soil electrical conductivity (EC) and cations (Ca^{2+}, K^+, Na^+). Heavy metals (As, Cu, Pb, Zn), soil basal respiration (BR), microbial biomass (C_{mic}) and nematode populations were determined. The highest level of TSN was found near the industrial enterprises, with 23.8 and 24.0 mg/kg at NavoiAzot and NavoiGRES, respectively. Soil sample pH was found to be weakly alkaline, with levels ranging between 7.9 and 8.1. Mean soil moisture content varied from 0.75% to 0.93% of the wet weight, without any significant differences between the sampling stations. The heavy metals As, Cu, Pb and Zn were accumulated in the upper soil layer. A significant difference was found between soil heavy-metal content for Cu (p<0.0005) and As (p<0.02). Basal respiration and microbial coefficient (C_{mic}/C_{org}) were found to be significantly negatively correlated with Cu and As soil content. A significantly positive correlation was found between the Cd concentration and the metabolic quotient (qCO_2) (p<0.003). No significant correlation was observed between the soil microbial population and total soluble nitrogen. Furthermore, the qCO_2, which is a known ecophysiological index for the soil microbial population, was found to be correlated with the total number of nematodes in general and with the bacteriovore-feeding group in particular. No significant correlation was observed between the soil microbial population and total soluble nitrogen.

Keywords: Nitrogen pollution; Heavy metals; Microbial biomass; Soil nematode community structure; Ecological indices; Soil pollution

1. Introduction

Nitrogen accumulation in the environment is a critical problem in our efforts to develop and implement plans for the sustainable management of natural resources. Human activities, both industrial and agricultural, have strongly increased the amount of biologically active nitrogen compounds, thereby disturbing the natural nitrogen cycle. Modern human activities associated with food production and fossil fuel combustion have greatly increased the cycling of active nitrogen through the atmosphere, hydrosphere and biosphere in alarming amounts (Mitchell et al., 2003; Driscoll et al., 2003). The inputs of nitrogen that accumulate in grasslands and forests initially increase productivity, followed by a decrease in biodiversity, which in the long run causes a decrease in productivity (Fangmeijer et al., 1994; Vitousek et al., 1997; Aber and Driscoll, 1997).

According to Mitchell et al. (2003), the rate of nitrogen accumulation in soil may decrease with the increase in gaseous and drainage losses. Airborne nitrogen accounts for only one-fifth of the total amount that humans set loose in nature, which is changing and moving more massively to the atmosphere, thus contributing to a more imbalanced system (Flucker and Braun, 1986; Wellburn, 1990; Fangmeijer et al., 1994; Fenn et al., 2003b) with disproportion-

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ately large effects on terrestrial systems (Department of the Environment, 1993; Takemoto et al., 1995; Seniczak et al., 1998; Fenn et al., 2003a).

Atmospheric deposition of nitrogen compounds can be considered as uncontrolled mineral fertilization, which occurs through dry deposition as droplets, gases and particles with a great importance as nitrogen input. Dry and wet depositions of nitrogen are considered an uncontrolled and unpredictable input as a source and have a great and significant input in terrestrial ecosystems. In urban systems, they are known to have different effects (Schlesinger et al., 1982; Lovett, 1994). In terrestrial systems, nitrogen pollutants stimulate the establishment of those plant species that need greater nitrogen levels, hence disturbing the natural dominance structure in these plant associations.

Recently published works of Mark E. Fenn et al. explore the effects of nitrogen deposition in the USA. In "Nitrogen emissions, deposition, and monitoring in the western United States" (Fenn et al., 2003a,b), they summarize the patterns of sources and emissions of nitrogen and the subsequent nitrogen deposition across the diverse landscape of the western USA. In "Ecological effects of nitrogen deposition in the western United States" (Fenn et al., 2003a,b), they suggest that the reductions of atmospheric emissions of nitrogen proposed as a way to protect ecosystems in many regions are not applicable in the west because of differences in climate, soils, forest characteristics and sources of emissions.

The effects of ammonium-rich air pollution, produced by a nitrogen fertilizer factory at Wloclawek (Poland), on arboreal and soil mites (Acari), was investigated in 20-year-old Scots pine forests by Seniczak et al. (1998). Their investigations showed that nitrogen input has a strong effect not only on plant communities, but also on plant litter accumulation and on the microclimate of the surrounding plant community, which is known to play an important role in the biological activity of terrestrial ecosystems.

There are many studies on the effects of nitrogen in the atmosphere. Attention has been drawn to the effects of nitrogen on vegetation, without emphasis on its impact on soil microorganisms. The objectives of this study were firstly to investigate the influences of nitrogen pollution on soil microbial characteristics and the soil free-living nematode community structure in soil samples from the different sampling sites surrounding a nitrogen fertilizer factory in the Navoiy industrial area. The response of soil biota to heavy-metal contents in the same soil samples was also examined in order to prevent misevaluation of real disturbances.

2. Material and methods

2.1. Study site and locations

The fieldwork was conducted in Navoiy City (40°5′N–65°22′E) on the Kyzilkum desert, near the river Zaravshan (Navoiy province, Western Uzbekistan). The region has a flat topography, with small hills reaching up to 200 m above sea level. The climate is typically continental, with hot and dry summers and cold, but not long winters. Annual mean temperature is 16 °C, the average monthly temperature in July is 27–32 °C. Annual precipitation is usually 100–200 mm, which is 5–10 times less than the evaporation. The north and northeast winds are typical for the plains. The northwest wind is mainly recorded in summer (United Nations Economic and Social Council, 2001). The soils at the study area are Calcic Yermosols (FAO, 2003).

Air quality in the vicinity of the Navoiy industrial area is poor. The volume of air pollutants per capita exceeds the Maximum Allowable Concentrations (MAC) fivefold in 20 major industrial areas of Uzbekistan. The Navoiy Industrial Park includes the Navoiy Azot complex, which is one of the country's largest suppliers of mineral fertilizers and is responsible for more than 5% of the country's emissions from stationary sources (Status of the Environment in Uzbekistan, 2001). The share of the chemical industry, which is situated in Navoiy, is approximately 3% of the total air pollution in this area. The main pollutants are ammonium nitrate, ammonia and nitrogen dioxide. The average annual concentration of nitrogen dioxide (50 $\mu g/m^3$) and ammonium (60 $\mu g/m^3$) in atmospheric air in Navoiy City is much higher than World Health Organization (WHO) standards (National Environmental Action Plan, 1999).

2.2. Soil sampling and extracting methods

The soil samples were collected from the 0–10-cm layer (n=4) at the Navoiy Industrial Park (location A) and the surrounding sites at a distance of 5 km from the pollution source in July 2003. Location B is situated 5 km north of the industrial park. Location C is a residential area 5 km east of the industrial park. Location D is an agricultural area 5 km west of the industrial park. Location E is a desert 5 km south of the industrial park (Fig. 1). Random soil samples were collected at each sampling site, placed in individual plastic bags and transported to the laboratory for chemical and biological component determination. The soils were kept in cold storage at 4 °C. Before biological and chemical analysis, they were sieved though a 2-mm mesh sieve.

2.3. Laboratory analyses

1. Soil moisture (SM) of the subsamples was measured gravimetrically as percentage of dry mass by drying the samples to a constant weight at 105 °C.
2. Soil salinity was determined in soil extracts and expressed as electrical conductivity (EC) ($\mu S\ g^{-1}$). Soluble cations (Ca^{2+}, K^+, Na^+) were determined by flame photometer (Rhoades, 1982).
3. Total organic carbon (C_{org}) was determined using a modified method of Rowell (1994). The method is based on organic matter oxidation by K-dichromate.
4. Total soluble nitrogen (TSN) in soil was determined by adding 25 ml 0.01 M $CaCl_2$ to 10 g subsamples and shaking for 2 h (Houba et al., 1987). The amounts of TSN in the soil extracts were determined using a Skalar Autoanalyzer unit (SFAS, 1995). All results are based on oven-dried soil.
5. Total concentration of heavy metals (As, Cu, Pb, Zn) was determined using the atomic absorption spectrometry

Fig. 1. Map of Uzbekistan and the location of the Navoiy industrial site (A, B, C, D, and E soil sampling locations).

(AAS) method. Subsamples from each sample were air-dried and pounded using an agate mortar until they turned into powder. Metals were extracted by digestion with three parts concentrated HNO_3 and one part concentrated $HClO_3$, and the concentration was determined using AAS.

(6) Soil microbial biomass (C_{mic}) was determined using a chloroform fumigation incubation (CFI) assay, according to Jenkinson and Powlson (1976). 5-g soil samples were adjusted to 40% water-holding capacity and fumigated in a $CHCl_3$-saturated atmosphere in a desiccator for 24 h. Then the fumigated and corresponding nonfumigated (control) samples were transferred to 0.5-L glass jars and incubated for 10 days at 25 °C in the dark. CO_2 concentration was measured in the headspace using a GC, and C_{mic} was calculated as

$$C_{\mathrm{mic}} = [(\mathrm{CO_2} - C \text{ from fumigated soil}) \\ - (\mathrm{CO_2} - C \text{ from control sample})]/kc$$

By using kc of 0.41, as proposed by Anderson and Domsch (1990).

(7) Soil basal respiration (BR) as CO_2 evolution was determined by GC (Sparling and West, 1990).

(8) Metabolic quotient [qCO_2] was calculated as the ratio between CO_2 production and microbial biomass (Anderson and Domsch, 1990). The qCO_2 is a specific parameter for

evaluating the effects of environmental conditions on the soil microbial biomass.

(9) Microbial coefficient, known as substrate availability, was determined as the C_{mic}/C_{org} ratio.

(10) Nematode population was determined by extraction from 100-g soil samples using the Baermann funnel procedure (Cairns, 1960). The recovered organisms were counted using a compound microscope and preserved in formalin (Steinberger and Sarig, 1993). All organisms in the samples were identified, mainly to genus level if possible, using an inverted compound microscope. Trophic groups were (1) bacteriovores (BF); (2) fungivores (FF); (3) plant-parasites (PP); and (4) omnivores–predators (OP) (Steinberger and Loboda, 1991; Steinberger and Sarig, 1993; Liang et al., 2000). The nematode community was analyzed by the following approaches: (1) absolute abundance of individuals 100 g^{-1} dry soil; (2) absolute number of trophic groups; and ecological indices: (a) Wasilewska index (WI), ratio of fungivores+bacteriovores to plant parasites [WI=(FF+BF)/PP] (Wasilewska, 1994); (b) Shannon Index (H'), a species diversity measure, which gives more weight to rare species, [$H'=-\sum P_i(\ln P_i)$], where P is the proportion of individuals in the ith taxon (Shannon and Weaver, 1949); (c) Maturity Index (MI), [$\mathrm{MI}=\sum v_i p_i$], where v_i, is the c–p value assigned by Bongers (1990) of the ith genus in the nematode and p_i, the proportion of the genus in the nematode community. The c–p values describe the nematode life strategies, and range from 1 (colonizers, tolerant to disturbance) to 5 (persisters, sensitive to disturbance); (d) Plant Parasite Index (PPI) is an ecosystem parameter based on life history characteristics of plant feeding nematodes coded as c–p values (Bongers, 1990).

The data presented in this study are reported as oven-dried weights. All data were subjected to statistical analysis of variance using the SAS model (ANOVA, Duncan's multiple range test and Pearson correlation coefficient) and were used to evaluate differences between separate means. ANOVA followed by Tukey's HSD test to establish the significance of differences between plot areas using the statistical package, Statistica 4.3. Differences obtained at levels of $p<0.05$ were considered significant.

3. Results

3.1. Soil characteristics

No significant differences in soil moisture and pH levels were found between the sampling sites. The soils were weakly alkaline, with a pH ranging from 7.9 to 8.1. The mean soil moisture content ranged between 0.75% and 0.93% (Tables 1, 2).

Soil electrical conductivity (EC) was found to reach its highest value of 3.67 mS g^{-1} at station B, located 5 km north of the industrial park (Table 1). A significant difference was found between location B and the other sampling locations ($p>0.006$; Table 2).

A spatial comparison of the cation content of soil samples from different sampling locations revealed that Ca^{2+} and Na^{+} concen-

Table 1
Main chemical characteristics of the soil samples (mean+standard deviation, $n=17$)

Sampling locations	C_{org} (%)	TSN (mg kg^{-1})	Sm (%)	pH	EC (mS g^{-1})	Ca^{+2} (mg kg^{-1})	Na^{+} (mg kg^{-1})	K^{+} (mg kg^{-1})	As (mg kg^{-1})	Cu (mg kg^{-1})	Pb (mg kg^{-1})	Zn (mg kg^{-1})
A	0.4±0.1	23.75±11.7	0.8±0.1	8.15±0.2	1.5±0.5	19±13.7	31±3.6	7±0	15.08±2	32±4.1	6.25±2.5	5.6±0.2
B	0.5±0.1	24±8.6	0.93±0.1	7.97±0.1	3.67±1.5	61.33±25.9	41.67±12.9	8.33±2.3	13.13±0.4	29±1	6.67±2.8	6.67±0.7
C	0.37±0.1	7.33±6.6	0.93±0.1	8.13±0.1	1.33±0.5	14±7.55	24.33±5.8	5±1.7	15.9±1.9	35.67±2.5	6.67±2.8	6.23±0.6
D	0.77±0.2	3.33±1.1	0.8±0.1	8.17±0.1	1.67±0.5	5±0.1	15.67±5.7	20.67±2.3	10.73±1.9	30.33±2.5	5±0.1	6.53±1.0
E	0.45±0.2	3.25±0.5	0.75±0.3	8.13±0.2	1±0.1	7±0.1	23.75±3.8	5.25±2.5	9.68±3.8	17.25±6.2	5±0.1	6.05±1.2

Table 2
Univariate analysis of variance (ANOVA) for soil condititions, heavy metals, microbial activity and nematode indices in pollution gradient of NavoiAzot

	Locations	
	F-test	*P* value
Soil condition		
Soil moisture (SM)	0.89	NS[a]
pH	0.71	NS
Electrical conductivity (EC)	6.03	0.006
Ca^{2+}	9.72	0.001
Na^{+}	5.8	0.007
K^{+}	34.48	<0.0001
Total organic carbon (C_{org})	3.88	0.03
Total soluble nitrogen (TSN)	7.2	0.003
As	4.26	0.02
Cu	11.13	0.0005
Pb	0.56	NS
Zn	0.8	NS
Soil microbial activity		
Microbial biomass (Mb)	4.55	0.02
Basal respiration (BR)	3.52	0.04
Metabolic coefficient (qCO_2)	3.99	0.03
Microbial coefficient (C_{mic}/C_{bio})	4.59	0.02
Nematodes trophic structure:		
Total nematode abundance (TNem)	5.23	0.01
Bacterivores (BF)	2.85	0.05
Fungyvores (FF)	1.57	NS
Plant-parasites (PP)	6.52	0.005
Omnivores-predators (OP)	4.34	0.02
Nematode indices		
Wasilevsky index (WI)	7.55	0.01
Shanon index (H')	4.01	0.03
Maturity index (MI)	4.7	0.02
Plant-parasite index (PPI)	4.61	0.02

[a] NS–nonsignificant difference.

trations in the soil near the Navoiy complex were higher than in the other sites. The K^{+} content in the soil samples was two and three times greater at location D than in the other three stations (Table 1). Data analysis demonstrated significant sampling location effect for Ca ($p>0.001$), Na ($p>0.007$) and K ($p>0.001$) (Table 2).

The mean total organic carbon (C_{org}) and total soluble nitrogen (TSN) contents varied considerably among sampling sites, with respective values ranging from 0.37% to 0.77% for C_{org} and from 3.25 to 24 mg/kg for TSN, with significant differences between sampling sites. The concentration of C_{org} exhibited a sharp increase at sampling location D, reaching a mean value of 0.77%, with significant sampling location effect ($p<0.03$). TSN content in soil samples decreased with distance from the industrial complex, from a mean value of 23.7–24 mg kg^{-1} to 3.3 mg kg^{-1} at locations D and E, which are 5 km from the industrial and urban sites. The change in TSN values among the sampling sites was statistically different ($p<0.003$) (Tables 1 and 2; Fig. 2).

3.2. Heavy metals

All studies undertaken in this area showed that the heavy metals As, Cu, Pb and Zn accumulated in the upper soil layer. In the present study a significant difference in heavy-metal content and distribution in soils was also found for Cu ($p<0.0005$) and As ($p<0.02$). The highest As and Cu concentrations were found in location A and C industrial and residential areas, with values of 15.9 mg kg^{-1} and 35.6 mg kg^{-1}, respectively. The lowest concentrations of Cu (17.2 mg kg^{-1}) and As (9.6 mg kg^{-1}) were found at site E. However, Cd was found in soil samples from location A only, and no significant differences were found in Pb and Zn content between the different sampling sites (Tables 1 and 2; Fig. 3).

The relationships between metal content and microbial activity were observed in polluted soils. High negative correlations were found between As, Cu contents and basal respiration (BR) ($p<0.002$, $r=-0.681$, $n=17$; $p<0.0001$, $r=-0.819$, $n=17$, respectively) and microbial coefficient (C_{mic}/C_{org}) with Cu ($p<0.02$, $r=-0.557$, $n=17$). The Cd concentration in the soil samples was found to be strongly correlated with the metabolic coefficient (qCO_2) ($p<0.003$, $r=0.674$, $n=17$) (Fig. 2).

3.3. Microbial biomass

Soil microbial biomass (C_{mic}) reached a maximal value of 571.7 and 322.6 µg $C \cdot g^{-1}$ soil in samples taken from the upper layer (0–10 cm) at locations B and E, respectively, which are located north and south of the industrial area (Fig. 4). At the other locations, which are perpendicular to this direction, including the industrial plant, the levels of microbial biomass was significantly ($p<0.02$) lower than in the north–south transect (Table 2).

Basal respiration (BR) showed a relative high CO_2 production at all sampling sites, except for the east site (location C), which had

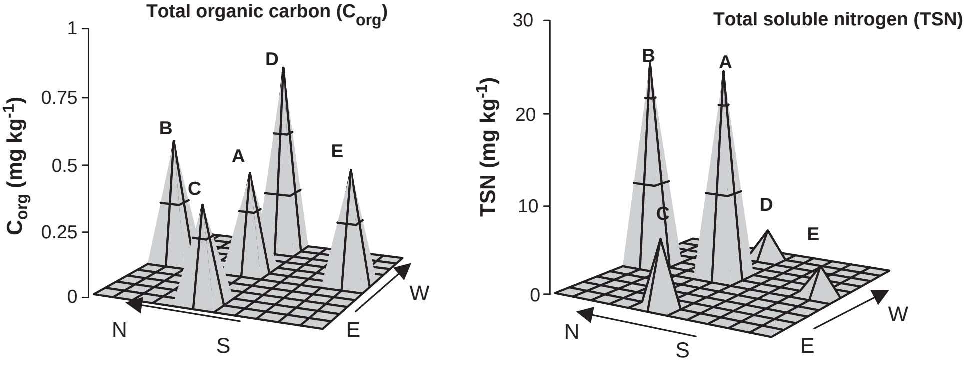

Fig. 2. Organic carbon (C_{org}) and total soluble nitrogen (TSN) levels in soil samples from the different sampling sites in the Navoiy industrial area.

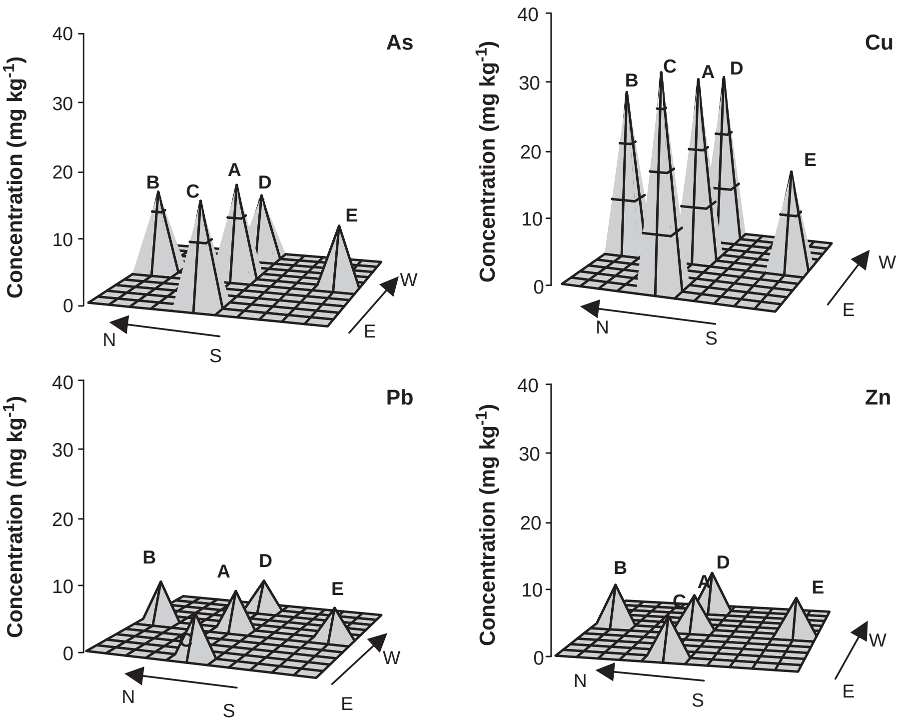

Fig. 3. Heavy-metal concentrations (As, Cu, Pb and Zn) in soil samples taken from the different sampling sites at the Navoiy industrial area.

a maximum threefold lower value of 150 μg CO_2–C (g soil · h)$^{-1}$ (Fig. 4). The data obtained on BR show a progressive decrease from west to east, followed by a similar trend from south to north, although station A (industrial plant) had the lowest value between the two (N and S). The different values obtained at the different sites yielded a significant difference (p<0.04) between locations

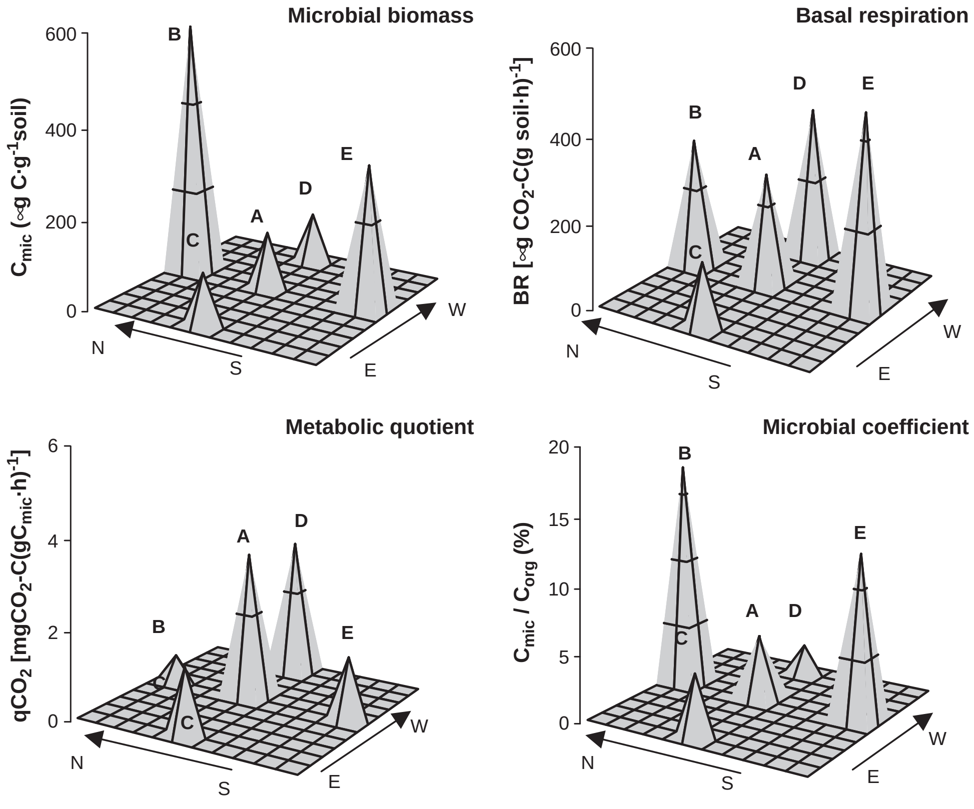

Fig. 4. Soil microbial biomass, basal respiration, metabolic quotient and microbial coefficient in soil samples taken from different sampling sites at the Navoiy industrial area.

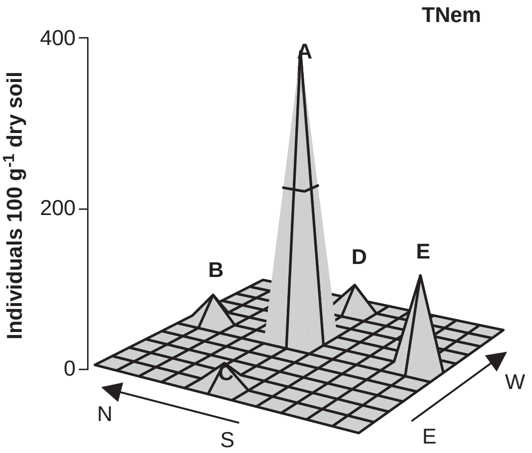

Fig. 5. Total nematode population in soil samples taken from different sampling sites at the Navoiy industrial area.

(Table 2). As a result of the significant changes in C_{mic} and BR at each location, the metabolic quotient (qCO_2) patterns obtained for the soil microbial community decreased from a maximal value of 3.3 to 0.61 mg CO_2–C (g $C_{mic} \cdot h)^{-1}$ along the deposition gradient (Fig. 4, Table 2), with lowest values at the northern, eastern and southern sites.

The pattern obtained for the microbial coefficients (C_{mic}/C_{org}) was different, with the highest values found in the north (17.0%) and south (12.5%) sampling sites and the lowest values in the cross section from west to east with values ranging between 2.3% and 5% (Fig. 4; Table 2).

3.4. Nematode population

The soil free-living nematode populations are presented in Fig. 5, with differences in total abundance between the sampling locations. Near the industrial plant a mean maximum population level of 367 individuals 100 g^{-1} dry soil was found. This high population density is significant ($p<0.001$) compared to the surrounding sampling sites, followed by location E which is located south with a 116 individuals 100 g^{-1} dry soil. At locations B, C and D, the mean nematode population density was 34, 27 and 33 individuals 100 g^{-1} dry soil, respectively, which is significantly ($p<0.01$) lower (Table 2) than in the other locations.

A significant positive correlation was found between the total density of the soil free-living nematode population and the TSN content ($r=0.48$, $n=17$, $p<0.04$).

3.5. Nematode genera and tropic groups

A total of 22 nematode genera were identified, including 9 bacteriovores, 3 fungivores, 7 plant-parasites and 3 omnivore-predators (Table 3).

The bacteriovore trophic groups were found to be the most abundant trophic group in the study area. A significant location effect was found ($p<0.05$) among the bacteria feeder nematodes (Table 2), reaching a mean maximum of 234 individuals 100 g^{-1} soil, represented by six families at location A (Fig. 6).

The plant-parasite population was the second most common trophic group, represented by four and seven families and reaching a mean maximum density of 120 and 52 individuals 100 g^{-1} soil at location A and E, respectively (Fig. 6, Table 2). Fungi feeder nematodes were found in low numbers and were represented by three families, two of which were found at sampling sites A and B. Sampling sites C and D were represented by only one family, while no fungivores were found at location E which is located south of the sampling site (Fig. 6), with no significant differences between sampling sites (Table 2).

The omnivore-predator free-living nematodes exhibited patterns similar to those of fungivores, i.e., low numbers, three representatives with different appearance, no representatives at station A and 1, 2, 1, 2 representatives at sampling sites B, C, D and E, respectively (Fig. 6). A significant ($p<0.02$) location effect was found in the low density of the omnivore-predator trophic group (Table 2).

3.6. Nematode taxa

A total of 22 taxa were found in the soil samples (Table 3), of which 12, 8, 7, 8 and 15 families were found at sampling locations A, B, C, D and E, respectively. *Panagrolaimus*, *Chiloplacus*, *Eucephalobus*, *Tylenchus* and *Pratylenchus* genera were the dominant taxa, with a relative abundance of 34.0%, 10.3%, 6.0%, 5.1% and 4.8% of the total nematode community, respectively (Table 3). All of the taxa were found at location A (pollution source). The *Panagrolaimus* and the *Chiloplacus* families were found in different densities at all four sampling locations. As presented in Table 3, genera belonging to bacteriovores and plant-parasite groups were the most abundant.

Table 3
Mean relative abundance (%) of soil nematodes in different sampling locations along the pollution gradient of Navoiy industrial complex

Locations		A	B	C	D	E	Mean[a]
Trophic groups/genus[b]							
*__Bacteriovores__	**c–p**	**63.7**	**69.6**	**65.5**	**82.6**	**47.4**	**65.8**
**_Acrobeles_	2	00.0	00.0	00.0	00.0	23.6	04.7
**_Acrobeloides_	2	03.2	00.0	00.0	00.0	00.0	00.6
**_Cephalobus_	2	02.5	16.3	00.0	01.9	01.3	04.4
**_Cervidellus_	2	04.4	00.0	06.3	00.0	00.0	02.1
**_Chiloplacus_	2	12.6	13.9	11.2	06.4	07.2	10.3
**_Eucephalobus_	2	01.2	00.0	12.3	15.0	01.3	06.0
**_Panagrolaimus_	1	39.9	39.4	35.8	42.4	12.6	34.0
**_Pelodera_	1	00.0	00.0	00.0	16.9	00.0	03.4
**_Wilsonema_	2	00.0	00.0	00.0	00.0	01.5	00.3
*__Fungivores__		**03.5**	**17.9**	**11.2**	**06.5**	**00.0**	**07.8**
**_Aphelenchoides_	2	01.1	13.6	00.0	00.0	00.0	02.9
**_Aphelenchus_	2	00.0	04.3	11.2	00.0	00.0	03.1
**_Nothotylenchus_	2	02.4	00.0	00.0	06.5	00.0	01.8
*__Plant-parasites__		**32.8**	**08.2**	**00.0**	**06.5**	**45.3**	**18.6**
**_Filenchus_	2	00.0	00.0	00.0	00.0	01.5	00.3
**_Heterodera_	2	12.8	00.0	00.0	00.0	04.4	03.4
**_Meloidoginae_	3	03.2	00.0	00.0	00.0	01.5	00.9
**_Pratylenchus_	3	08.8	00.0	00.0	06.5	08.5	04.8
**_Tylenchorchinchus_	2	00.0	04.3	00.0	00.0	14.6	03.8
**_Tylenchus_	2	08.0	03.8	00.0	00.0	13.5	05.1
**_Telotylenchus_	2	00.0	00.0	00.0	00.0	01.3	00.3
*__Omnivore-predators__		**00.0**	**04.3**	**23.2**	**04.3**	**07.2**	**07.8**
**_Dorylaimus_	4	00.0	00.0	12.0	00.0	00.0	02.4
**_Eudorylaimus_	4	00.0	04.3	11.2	04.3	03.7	04.7
**_Nygolaimus_	5	00.0	00.0	00.0	00.0	03.5	00.7

[a] Mean of nematode density in study area.
[b] By classification of Yeates and King (1997) and Liang et al. (2000).
* Trophic groups.
** Genus.

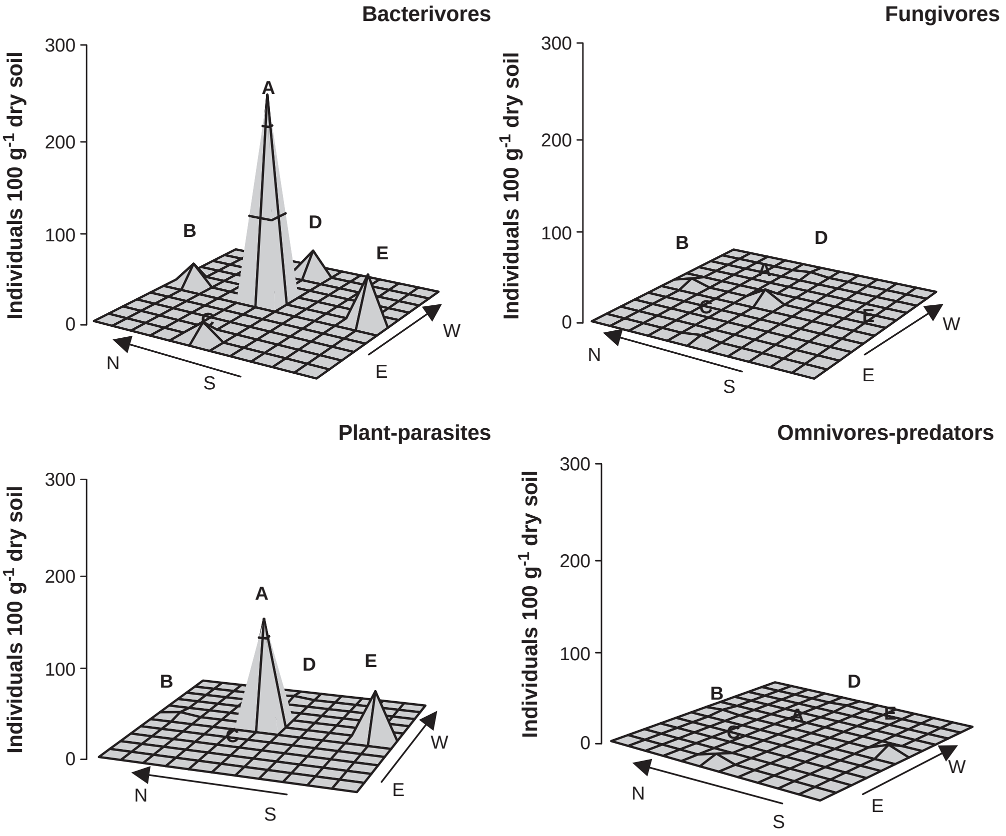

Fig. 6. Nematode trophic groups in the soil samples taken from the different sampling sites at the Navoiy industrial area.

Representative genera of the fungivore and omnivore-predator trophic groups were found infrequently in the study area.

3.7. Ecological indices

The ratio of bacteriovores and fungivores to plant parasites (WI), which is known to show substantial changes in the trophic structure of nematode communities (Wasilewska, 1994), was found to exhibit a significant pattern for the N to S transect, compared to the E to W transect, yielding ($p<0.01$) differences between the locations (Fig. 7, Table 2). The values obtained at the east sampling site as well at the south were found to reach a mean value of X and Y, respectively, with WI values being relatively higher at the north and west sampling sites and reaching values of Z and Q, respectively (Fig. 7).

The Shannon Index (H') (Fig. 5) exhibited different trends between the cross sections. The north–south transect exhibited a continuous increase in H', yielding a significant ($p<0.05$) difference between the sampling sites, whereas no significant differences were found between the sampling sites at the east to west cross section.

The maturity index (MI), which is based on the life-history strategy characteristics of nematode taxa and reflects the degree of disturbance of the soil ecosystem, exhibited a significant decrease from north to south and from east to west sampling sites (Table 2). This trend reflects the level of soil system disturbances at the different sampling sites.

The plant-parasites index (PPI), which shows the relative changes in ecosystem parameters based on life-history characteristics of plant-feeding nematodes, was found to exhibit two different patterns, one for each transect. The north–south transect was found to increase with the direction, exhibiting a significant ($p<0.03$) difference between the two extremes. However, the east–west transect exhibited significantly lower values than the other sampling sites (Fig. 5).

4. Discussion

Studies of nitrogen and heavy-metal contents in the soil samples from the Navoiy industrial area have shown that there are strong spatial patterns of nitrogen and heavy-metal input from atmospheric deposition in this area. High concentrations of nitrogen were found near NavoiAzot (nitrogen fertilizer factory) and NavoiGRES (power plant), which are the main emitters of nitrogen-containing pollutants in this area. Nitrogen-containing air pollutants and heavy metals can affect soil fauna (microbial biomass and nematode community structure) directly, after being deposited on soil, plants or water or indirectly, via changing soil microclimate and food sources. In present study, no significant correlation was found between the soil microbial population and total soluble nitrogen. However, the index of the ecophysiological condition of the soil microbial population, qCO_2, was affected by the total number of nematodes ($p<0.05$, $r=0.490$, $n=17$) and by the bacteriovore

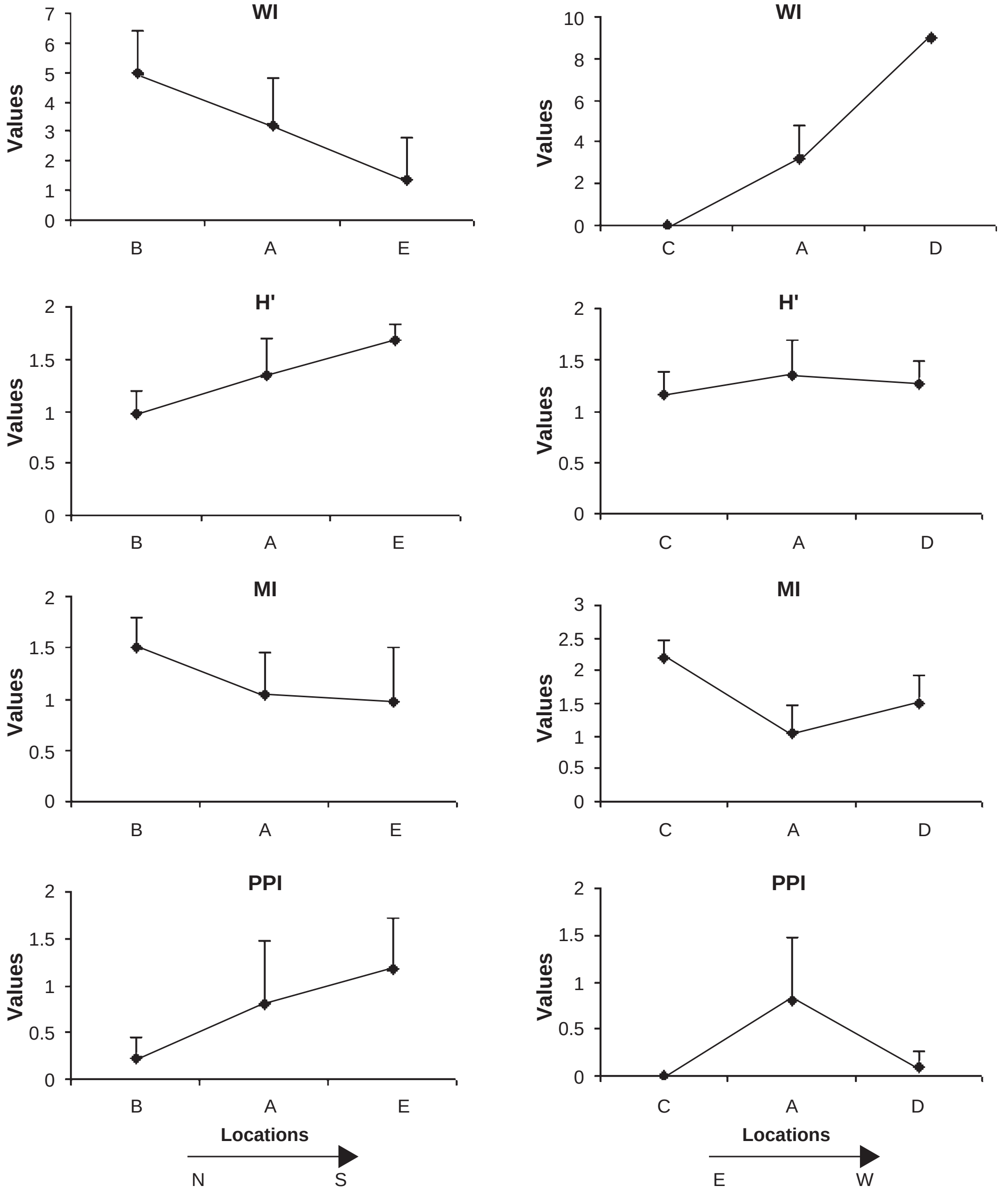

Fig. 7. Indexes of nematode population along the north–south and east–west transects of the sampling sites at the Navoiy industrial area.

trophic group ($p<0.01$, $r=0.615$, $n=17$). An intermediate level of nitrogen pollution in soils at locations D and E was associated with an overall increase in basal respiration (BR) (370.7 and 461.3 μg CO_2–C (g soil · h)$^{-1}$, respectively).

Significantly close relationships were observed between metal content and microbial activity in the studied soils. Basal respiration (BR) and microbial biomass–total organic carbon ratio (C_{mic}/C_{org}), had a significantly negative correlation with Cu and As soil contents. A significantly positive correlation was found between the Cd concentration and the metabolic quotient (qCO_2) ($p<0.003$, $r=0.674$, $n=17$) (Fig. 2), which represents a specific physiological status, evaluating the effect of soil contamination on the soil microbial community. This might explain the reduction of microbial biomass and the increase in the qCO_2 values in the high Cd soils, thus confirming earlier reports (Brookes, 1995).

The nitrogen pollution significantly influenced the total number of nematodes and the distribution of nematode communities. Soil total nitrogen content was correlated with the total density of nematodes ($p<0.05$, $r=0.483$, $n=17$) and the plant-parasites trophic group ($p<0.02$, $r=0.548$, $n=17$). Analysis of the distribution of the nematode trophic group structure by locations showed a change in the ecosystem. High levels of nitrogen pollution in the vicinity of the Navoiy Industrial Park were associated with an overall increase in the density of plant-parasites and bacteriovores trophic groups.

The plant-parasite population reached maximum values near NavoiAzot. The reason for this may be due to the atmospheric input of nitrogen pollution in the soil ecosystem. Nitrogen pollution can change plant associations and can undoubtedly modify the soil microclimate and biological activity (Seniczak et al., 1998) and can increase plant parasites near NavoiAzot.

A high concentration of nitrogen and heavy metals can be toxic to soil biota (Moursi, 1962; Warren, 1962; Huhta et al., 1967). It is probably responsible for the decreased OP and FF in the most polluted sampling location A. In this study, a negative bioindicative response to nitrogen and heavy-metal pollution was most evident amongst the omnivore-predators and fungivores trophic groups.

The present study was performed in order to assess the specific effects of long-term atmospheric exposure to elevated concentrations of nitrogen and heavy metals, as the main contaminants, on the microbial community and the nematode trophic composition. The results of the study indicate that the direct and indirect effects of industrial pollution on the soil microbial biomass and the nematode community in the vicinity of around Navoiy industrial complex were as follows. (1) The plant-parasite population reached maximum values in the vicinity of NavoiAzot. (2) An abundance of bacteriovore near the factory is based on stimulation of microbial community. (3) The soil microbial population, the fungivores and the omnivore-predator trophic groups were very sensitive to pollution.

This study emphasizes the importance of soil biota use as a bio-monitoring tool in terrestrial ecosystems.

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